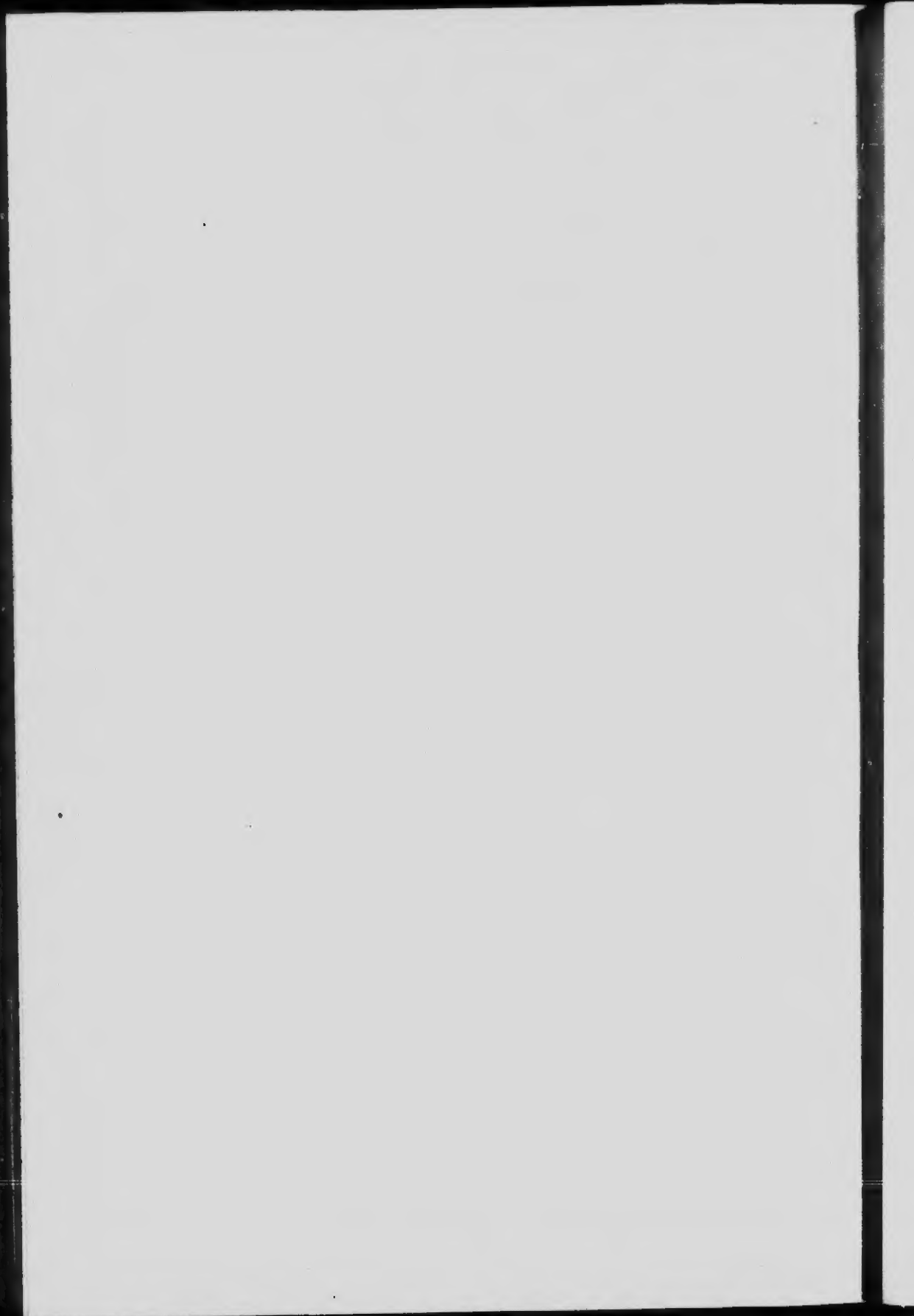


THE PALÆOCHEMISTRY OF THE OCEAN IN RELATION
TO ANIMAL AND VEGETABLE PROTOPLASM

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I.—INTRODUCTION

THE history of the composition of ocean water is a question of very great interest to the geologist, the physiographer and the biologist. To the geologist and physiographer its importance lies chiefly in the fact that it is associated with the history, on the one hand, of erosion and denudation of land surfaces of the globe, and, on the other, of the formation of all the sedimentary strata. The ocean, ever since the first condensation of water on the rockcrust of the earth, has acted as a gigantic solvent, and the salts it now holds in solution represent what it has retained after its action for millions of years as a leaching and filtering agent. The sedimentary rocks are thus but a vast precipitate from the ocean of what had been partly suspended and partly dissolved matter in it during all the geological periods. The history of the composition of the ocean is, on this view, the complement of the history of all the terrigenous changes necessary to fill out all the pages of the record of events that have transformed the surface of the earth.

To the biologist the value of the question obtains from a different point of view. The sea is the original home of all life on the globe, and it was in the sea that the differentiation between animal and vegetable life, as well as the evolution of the great divisions of the animal kingdom were effected. Indeed the great events in the evolution of animal forms have been rendered possible by changes which have taken place in the composition of ocean water. These changes have modified organisms, and have created conditions which have served as factors in directing the course of development. This may be specially illustrated by reference to the case of the calcium salts in sea water. That the earlier Archæan seas contained comparatively small quantities of calcium compounds seems to be clearly indicated by the fact that in pre-Cambrian strata the limestone deposits are very limited, not more than two per cent. of the thickness of the beds, the Huronian portions of which, now generally recognized as of sedimentary origin, are, according to Lawson,* over 50,000 feet in thickness. The small amount of limestone deposits could not have been due to the absence of living organisms, for the oldest Cambrian beds contain Trilobites and Brachiopods, and such highly specialized forms postulate a long course of pre-Cambrian life. The very fact that the Brachiopods of the early Cambrian were largely those provided with a horny or chitinous shell, indicates that all the animal forms of the preceding period had imperfectly acquired the lime "habit," which, one may reasonably believe, would have earlier made its appearance had calcium salts been present in considerable quantities in ocean water from the first. It is perhaps due to the absence of this lime "habit" that fossils do not obtain in pre-Cambrian strata.

Once, however, the lime "habit" was acquired, through adaptation of the animal cell to its environment, the course of development became accelerated, and the evolution of the higher types of Invertebrate life, as well as all the forms of Vertebrata, became possible. The Vertebrate skeleton, and all that it implies in evolution, is, therefore, a result of the gradual increase in the quantity of calcium in the oceans of the pre-Cambrian period.

To both the geologist and the biologist the history of the chemistry of the ocean has recently acquired an additional interest from the attempt made by Joly† to determine the age of the earth, who uses for that purpose as factors the amount of sodium now in the ocean, and that

* Geol. Survey of Canada, 1887, pp. 101 and 102, F.

† An Estimate of the Geological Age of the Earth. Trans. Roy. Dublin Soc., Vol. 7. (Ser. 2), 899, p. 23.

estimated to be in the annual river discharge of the globe. Joly took for these the results of Murray,* who, basing his calculations on the discharge of nineteen of the principal rivers of the world, estimated the total amount of the sodium and other salts annually put into the sea by river water. Joly finds from Murray's tables that the sodium annually discharged is 157,470,000 tons, and the quantity in the sea is 14,151,000,000,000,000 tons. Dividing the latter by the former he gets as quotient, approximately, 90,000,000, which, expressed as years, would be the age of the earth, or, rather, the period of time which has elapsed since the first condensation of water vapour took place on the globe. Joly admits that the ocean at first contained a considerable quantity of sodium as sodium chloride, and this he puts at about 14 per cent. of the present amount in the sea. This would make the amount discharged into the sea by river water less than that stated above, but, on the other hand, the volume of the ocean may, as a result of more recent estimations, be given a higher value, and in consequence the mass of sodium in it would be 15,627,000,000,000,000 tons. Further, of the sodium annually put into the ocean, Joly allows as much as 10 per cent. for that which is taken from the ocean by the rain and returned again in river water, and this estimate would make the amount of river sodium, which is annually leached out of the rocks and strata, as 97,800,000 tons. With these values Joly finds that the corrected figures for the age of the earth is 89,300,000 years.

In support of his contention Joly shows that as compared with the igneous rocks there is in the sedimentary rocks, which are derived from them, a deficiency of sodium, and that the sodium now in the sea would approximately account for the difference. The bearing of this fact is that all the sodium now in the ocean was derived from the original rock crust by processes which to-day are in operation in decomposing rock material and removing the sodium therefrom. In other words, the discharge of sodium into the sea has been in the past a uniform one, or at least subject to no great variations that would constitute a factor against determining the age of the earth by this method.

This estimate has been ably criticized by the eminent geologist, the Rev. Osmond Fisher,† who points out that the sodium which is derived from the decomposition of crystalline or igneous rocks is in the form of carbonate rather than chloride; and he asks whether it is not possible that the chloride of river water is derived, not from crystalline,

* On the Total Annual Rainfall on the Land of the Globe, and the Relation of Rainfall to the Annual Discharge of Rivers. *The Scottish Geogr. Mag.*, Vol. 3, 1887, p. 65.

† *Geol. Mag., New Ser.*, Vol. 7, p. 124, 1900.

but from sedimentary rocks, or from what Sterry Hunt calls "fossil sea water, still to be found imprisoned in the pores of the older stratified rocks, and presumably in the younger as well." To answer this affirmatively would be of necessity to assert that the sodium which now goes to the sea as sodium chloride comes from the supply derived from and deposited by the sea in ancient geological strata—that is, what was at one time in the sea is being returned to it again. Fisher also points out that the strata which are now in the process of formation, imprison sodium chloride in their mass, taking it from the sea. There would thus be a constant circulation of sodium chloride from the ocean to the stratified rocks and back again to the ocean. That would also postulate that the sea was almost as rich in sodium chloride in Silurian times as it is now, and it would go far to support the view that "the sea was salt from the first;" but if we assume that the sodium of the sea is derived from those sodium compounds supplied by rivers other than the chloride, the estimate of the age of the earth, as given by Joly, would have to be multiplied several times in order to get the approximate length of the period which has elapsed since the oceans of the globe were first formed.

Another criticism of Joly's view, made along the lines followed by Fisher, is that advanced by Dubois,* who, from a comparison of the amounts of sodium and chlorine supplied to the sea by a large number of rivers, concluded that only a small portion, if any at all, of the sodium derived from denudation appears in river water as sodium chloride; that the sodium chloride discharged into the sea annually is derived from the rainfall, and the salt deposited in the older strata by the sea.

As Fisher has already pointed out, it is the sodium compounds other than the chloride that ought to be considered as being primarily derived from the disintegration of rock mass, and, therefore, primarily added to the sea. What the total amount of this sodium is cannot be determined with approximate certainty, but Dubois is inclined to regard it as about one quarter of the total discharge of sodium into the sea as given in Murray's tables, and, consequently, Joly's estimate of the length of the period which has elapsed since water first condensed on the earth's surface would have to be multiplied by four, the product being approximately 400 million years.

* On the Supply of Sodium and Chlorine by the Rivers to the Sea. Kon. Akad. v. Wetensch., Amsterdam. Proceedings of the Section of Sciences, Vol. 4, p. 388, 1902.

II.—THE ORIGIN OF THE PHYSIOLOGICAL RELATION OF THE CHEMICAL ELEMENT IN BLOOD PLASMA.

I have thus dealt at some length upon the importance of the history of sea water, and with Joly's views and those of his critics, because all this leads up to a question which is of very great importance to the physiologist. The life of the globe in the earlier geological ages, so far as the strata reveal to us the past history of the earth, as already pointed out, was closely associated with the sea. It is indeed almost universally assumed that life began in the ocean and continued in association with it alone till the close of the Cambrian period, although the presence of graphite in Cambrian and older rocks seems to indicate that vegetable organisms were accommodating themselves to a land life. Even this may not be an exception, for these rocks must have been laid down under water, and therefore their organic remains would be those of the sea. If accordingly we could know what the composition of the sea water in the Cambrian and pre-Cambrian periods was, we would, in all probability, be able to determine some of the chemical and physical forces to which living matter was then subjected and thus explain the relations which obtain to-day in living matter between it and its salts. In a recent paper* I have pointed out that the relative proportions of the elements, sodium, potassium, and calcium in the plasma of the blood are surprisingly very like those which are found in the ocean water of to-day, and that the differences which obtain between the two series of proportions of these elements may be explained on the ground that such proportions in the blood plasma are those that obtained in ancient sea water when the ancestral form of Vertebrates, in which sea water was the circulatory fluid, as it is in many marine forms to-day, acquired a closed circulatory system. That the ancient proportions are reproduced to-day in all forms, which have a closed circulation, I attribute to the influence of heredity, the cells of the organisms having for ages been associated with the sodium, potassium, and calcium in certain proportions, and having been accommodated to them, the relations ultimately became so fixed that living matter reproduces the ancient proportions in the fluids which bathe itself. There is one point in which the proportions in the circulatory fluid and those in sea water differ, and that is in respect to the magnesium. In the sea water of to-day there are 11.99 parts of magnesium for every 100 of sodium, while in plasma there are 0.8 parts of magnesium to 100 of sodium. This is

* On the Isorganic Composition of the Medusae, *Aurelia flavidula* and *Cyanea Arctica*. Journ. of Physiol., Vol. 29, p. 213, 1903.

a striking difference but it is easy of explanation. The proportion of magnesium in sea water is now slowly growing. In the pre-Cambrian oceans it must, therefore, have been very small, not perhaps as low as it is in blood plasma, for in the latter the magnesium would only represent the proportion of an earlier period than that in which the circulation became closed, as the tissues would only reproduce the proportion which had by long accommodation become fixed in them. Even the organisms which live in the sea to-day, whose ancestral forms have lived in the sea since the Cambrian, do not take up the magnesium from the sea water in the full proportion which it has in the latter.

III.—THE ORIGIN OF THE RELATION OF THE CHEMICAL ELEMENTS WITHIN PROTOPLASM ITSELF.

There is, therefore, so far as the circulatory fluid of Vertebrates is concerned, a reproduction of the proportions of the sodium, calcium, and potassium of the pre-Cambrian oceans. The problem which now arises is one whose solution involves greater difficulties. If organisms should reproduce in their own circulatory fluids the proportions of the elements in the early geological periods, what contributed to those remarkable proportions which obtain, not in the circulatory fluids, but in the living matter itself? These proportions are widely different from those found in the circulatory fluids, and one cannot bring oneself to regard the former as derived from the latter. In vegetable organisms the potassium and the calcium much exceed the sodium, and even the magnesium may be greater in amount than that of the latter. In animal organisms the proportions are difficult to ascertain owing to the presence of skeletal and other structures in which the calcium and sodium greatly preponderate, but even in these the potassium is nearly equal to the sodium, and in muscle it is greatly in excess, while the calcium and the magnesium are much less than the sodium. Thus, in the muscle of the dog the relative values for each are* :—

Na.	K.	Ca.	Mg.
100	354	7.26	25.1

These proportions may or may not represent approximately those found in unicellular organisms like an *Amoeba*, or even a white blood corpuscle, but do they represent to any degree the proportions which obtained in the early pre-Cambrian seas when life was represented by unicellular organisms only, which accommodated themselves to the sodium, potassium, calcium, and magnesium in their habitat, just as the

* Julius Katz, *Pflüger's Arch.*, Vol. 53, p. 1, 1896.

marine unicellular organisms of to-day have accommodated themselves to these elements in the sea water? If the blood plasma of Vertebrates, because of the forces of heredity, reproduce the proportions which obtained in pre-Cambrian oceans, why should not the cells of the tissues because of the same forces, reproduce in themselves the proportions which obtained in sea water of a much earlier geological period? In other words, if the proportions in the plasma are inherited, why should not those found in the living matter be considered as inherited also? An affirmative answer to this question would postulate that the proportions of the four elements in early pre-Cambrian seas were very greatly different from what they are now in the ocean—as different almost as the proportions of the four elements in muscle are from those found in the blood plasma.

The question is one of great importance in physiology, and, though its solution presents great difficulties, its very interest compels a consideration of it. We know that the unit of living matter, the cell, whether of animal or vegetable kingdom, presents, on the whole, the same type of structure, and it goes through the same morphological changes. Some of these are grouped under the process of division, and its characteristic details are the same in both animal and vegetable forms. Now, the animal and vegetable cells are derived from a single type which must have existed at the very dawn of life on the globe. The whole process of division, with its peculiar morphological features, was elaborated in this single-celled organism, which transmitted it to its descendants. Since, as already stated, the process of division is the same in both kingdoms, it is obvious that it has continued almost unchanged through an infinity of generations, animal and vegetable, and for many millions of years, and that this preservation of the original type is due to heredity. If, now, heredity is so powerful in regard to structure, is it a negligible force in regard to chemical composition? Is living matter fixed in structure almost beyond change, however widely the conditions under which it lives may vary, but unfixd and changeable in its relations to the chemical elements? As structure depends so largely on composition, it would be difficult to explain how living matter could so widely vary its relations to the elements and at the same time retain its structure.

We are, therefore, forced to a choice of hypotheses of which one postulates that all of the relations of living matter to sodium, potassium, calcium and magnesium are a result of inherited forces, while the other concedes that in regard to the circulatory fluids the proportions are

determined by heredity, but the relations of these elements in living matter itself are due to quite different forces in which heredity is a small factor or no factor at all. The acceptance or rejection of either hypothesis depends on the evidence which we can bring as to the composition of the ocean in the very earliest geological periods.

The conclusions which we can formulate on this point depend on what we accept as the composition of the original crust of the lithosphere, and in our knowledge of the character and composition of the sedimentary rocks, and they must also be based on the changes which are admitted to have taken place in the composition of the ocean during all the periods. These conclusions I propose to deal with here in a general way only, for a full consideration of all the facts which have a bearing on them would demand a detailed treatment which would far exceed the limits set for this paper.

IV.—THE COMPOSITION OF THE PRIMEVAL OCEAN.

The original condition of the earth was a molten mass in which the temperature was so high that many of the elements now in the rock crust were in a gaseous condition, and dissociated, just as they are at present, in the solar atmosphere. As the dissipation of heat went on some of these must have condensed at degrees of temperature which approximated their present respective volatilization points, while the remainder, oxygen, hydrogen, chlorine, sulphur and carbon would combine to form water, hydrochloric, sulphuric and carbonic acids. The elements, sodium, potassium, calcium, magnesium, and aluminum would also before condensation take out of the original atmosphere chlorine, sulphuric acid, oxygen, and perhaps, carbonic acid, to form the chlorides, sulphates, oxides, and carbonates of these elements, but whether these compounds obtained after condensation depended on whether the temperature of the heated rock surface was still as high as their respective dissociation points. When the molten magma had cooled down to a degree below the lowest dissociation point, all the compounds referred to would be either deposited on the hot rock surface or in the form of vapour in the then atmosphere. When the temperature of the latter had fallen to about 1000°C , all these compounds were removed by condensation, for although, under the atmospheric pressure which now obtains, the temperature of condensation is for nearly all these compounds about 200° lower, the very great atmospheric pressure of the pre-oceanic period must have rendered the

combination of the dissociated elements and the condensation of the compounds formed from them possible at a much higher temperature.*

At such a temperature the previously molten rock had become rigid, and of course the condensed compounds would be deposited on its surface, and when refusion of the rockcrust occurred, as it must have done over large areas, large quantities of the deposited compounds would be diffused through the superficial crust. When the cooling of the atmosphere and globe progressed until the temperature of the former was 370°C , the first condensation of water took place on the rock surface. The atmospheric pressure, according to Joly,† must have been about 270 times what it is now. According to Clarke's‡ estimate of the relative values of water and carbon dioxide to that of the solid portion of the globe, the atmospheric pressure before the first condensation took place, was about 247 times what it is at present. Joly affirms that at 370°C a pressure of 190 atmospheres would produce a condensation of water, and, as the pressure was much higher, condensation would go on till the pressure fell below 190 atmospheres. This would entail rapid evaporation, for at many points the temperature of the rock surface would be so high that the water would condense only to boil away immediately. This would collect the salts deposited on the surface in masses, and it would, as in the case of the chlorides of magnesium, iron and aluminium, convert these into oxides of these metals and free chlorine, which, uniting with hydrogen, would form free hydrochloric acid. The other chlorides, namely, those of sodium, potassium and calcium would be unaffected. The ferric chloride would in some cases be volatilized but to be recondensed.

This condensation of the water vapour, and the re-evaporation would occur a countless number of times before there would obtain a permanent body of water on the globe. Where such first occurred there would be a lower temperature than elsewhere, and in consequence further condensation of water vapour would occur there also. The result would be the first ocean basin, the weight of the body of water acting on the

* The volatilization points of potassium, sodium and magnesium are 667°C , 742°C , and 1100°C respectively. The melting points of calcium and aluminium are unknown. The melting points of certain sodium and potassium compounds are, according to V. Meyer & Riddle (Ber. d. d. Chem. Gesell. Vol. 27, p. 2443,) as follows:

Na Cl.....	851°C .	K Cl.....	766°C .
Na Br.....	727°C .	K Br.....	715°C .
Na I.....	650°C .	K I.....	623°C .
Na ₂ CO ₃	1098°C .	K ₂ CO ₃	1045°C .
Na ₂ SO ₄	843°C .	K ₂ SO ₄	1073°C .

† *Op. cit.*

‡ F. W. Clarke, The Relative Abundance of the Chemical Elements. Bulletin U. S. Geol. Survey No. 76, 1891.

thin crust and easily affecting the depression. These phenomena would be repeated at other points as the temperature of the crust and the atmosphere gradually lowered, until at a point below 100°C . nearly all of the water originally present in the atmosphere had condensed to form the oceans of the globe.

The composition of the ocean would follow from the occurrence of the soluble chlorides, sulphates and carbonates of the metals which came in contact with the first condensations. As pointed out, the condensation of superheated water would convert the chlorides of magnesium, iron and aluminium into magnesia (Mg O) oxide of iron (I_2O_3) and alumina (Al_2O_3), the first of which is soluble only in 55368 parts of hot or cold water,* while the two latter are practically insoluble, even in dilute acids. The magnesia, of course, would dissolve in water which contained either hydrochloric or carbonic acids, but the amount dissolved would, on account of the slight quantity of these acids in the water, be very small. The other chlorides, namely, those of sodium, potassium and calcium, although equally abundant, would not be leached out of the rock surface in equal amounts. The solubilities of these salts differ. For example, 100 parts of water dissolve at 99°C 154 parts of calcium chloride, 56.3 parts of potassium chloride, but only 39.7 parts of sodium chloride. In consequence there would be different quantities of each chloride dissolved, and the calcium chloride would by far predominate, while the potassium chloride would be more abundant than the corresponding sodium compound. There would, as already pointed out, be very little ferric chloride and what would be dissolved would gradually all be converted, first into the colloidal ferric hydrate, and eventually into the insoluble oxide of iron.

It does not follow that the ocean would contain, even after a long period of action on the rockcrust, the whole of the chlorides of calcium, potassium and sodium originally disposed over and diffused through the now more or less rigid rockcrust. The constant washing out of the land areas would no doubt tend to remove these salts from the rocks until there would be little left in the latter and at the same time they would become correspondingly more abundant in the sea water. But other salts would begin to appear there also. The magnesia derived from the chloride of magnesium, through the action of superheated water, would, under the action of carbonic acid in the rain water go into solution as carbonate, but the amount so dissolved, would, on account of its low degree of solubility, be very small and it would only

*Frobenius, Liebig's Annalen, Vol. 59, p. 103.

after a long period of time become appreciable in the ocean. The carbonic acid in the rain water must have acted, as it does now, on the silicates of sodium, potassium and calcium in the rocks and produced free silica and carbonates of these elements, these latter going into solution and thus reaching the ocean, where, acting on the chloride of calcium, carbonate of lime and chloride of sodium and potassium would be formed. The calcium carbonates would be removed by deposition and thus constitute the origin of the limestone beds of the pre-Cambrian age, but the chlorides remaining in solution, thus contributed to an increase in the amount of sodium and potassium in the sea water.*

The sulphates in the rock crust disintegrated or affected would also be carried to the sea, but, as these would be small in quantity, they need not be specially considered here.

Thus the history of the sea must have begun and continued for a period of unknown length. The only change came from the discharge into the sea of the carbonates, the consequent removal of the lime and the slow increase in amount of magnesium, sulphuric acid, and of potassium and sodium. The two latter elements were not removed from the sea except through the rainfall. As I shall presently point out, the potassium compounds are to-day removed from the ocean apparently as rapidly as they are added by river water, and, in consequence, the amount in sea water now appears to be stationary. In the earliest geological period the conditions which now contribute to this result did not exist, and the ocean retained all the potassium it held or received through river discharge. In all probability the potassium equalled, and even exceeded, the sodium in amount.† When sediments began to form, and, when soils made their appearance, then, and then only began the elimination of the potassium from the ocean. It has been long established that potassium manifests a marked capacity to unite with silicates of alumina to form firm compounds, and these obtain whenever potassium salts in solution come in contact with argillaceous material, sedimentary or otherwise,‡ while the sodium, magnesium, and calcium are unaffected.

* Sterry Hunt (Chemical and Geological Essays, Boston, 1873) held the view that the most abundant constituent in primeval sea water was calcium chloride, and that with the gradual addition of sodium carbonate calcium was removed as carbonate and sodium chloride consequently took its place.

† Joly (*loc. cit.*) assumes that the greater part of the chlorine now in the ocean was originally united with the iron, calcium, magnesium, potassium, and sodium, these elements entering into combination in proportion parallel to the proportions in the rockcrust as determined by F. W. Clarke (*loc. cit.*) This postulates that 14 per cent. of the chlorine now in the ocean was united with sodium, and consequently the ocean originally contained about one-seventh of the sodium it now holds. As the proportion of sodium to potassium in the rock crust is 100 to 95, on Joly's hypothesis the potassium in the primeval ocean must have really equalled in amount the sodium therein. Joly, however, is in error in supposing that the chlorides of magnesium and iron could have existed, and he should consequently have made a greater allowance for the amounts of chlorine combined with the sodium, potassium, and calcium.

‡ Sterry Hunt (*op. cit.* p. 93.)

The capacity to abstract the potassium is increased if the silicates are mixed with organic matter. Consequently the potassium which rain water may contain is in great part removed when the latter filters through soils, and, therefore, the water discharge from alluvial areas is always richer in sodium than potassium. This capacity of soils to abstract potassium is a matter of direct demonstration, and it "explains the presence of so small an amount of potassium salts in the waters of rivers, lakes, streams, and oceans where the lime and soda have accumulated."* This cause of deficiency acts not only in the case of the potassium leached out of disintegrating rock by rain water, but also on the potassium carried from the sea to the land areas by rain water. The potassium thus carried is not inconsiderable, for, according to M. J. Pierre,† the rain water in the neighbourhood of Caen (France) annually carries to each hectare of land, about 7.9 kilograms of this element, or about 1.23 tons per square mile.

This mode of elimination also operates in the ocean, where, however, the organic matter responsible for the removal, is derived from plankton organisms, which, on dying, fall to the sea bottom and their remains decomposing, the potassium they hold reacts with the argillaceous material on which the deposits rest and forms the mineral known as glauconite, containing as low as 0.95 per cent. of oxide of potassium, but other estimates range from 2.52 to 4.21 per cent. The sodium present is very much less in quantity.‡ This mineral is now being formed, as it has been formed in the past, on the ocean bottom over the areas which fringe the continental coasts and it constitutes as much as, or more than, half of the deposits in shallower waters. Considering the extent of these areas as well as the fact that they cover the sea bottom of those localities into which river discharge takes place, it will be recognized what a very important factor the constant formation of glauconite is in eliminating potassium from sea water and thus preventing an increase in the amount of that element in the ocean. This formation has been going on in the past geological periods, for it is to be found§ in the primary formations of Russia and Sweden, in the sands

* Mendeleef's Chemistry, Vol. 1, p. 547, 1897.

† The reference is given in Dr. Angus Smith's "Air and Rain," which is quoted by Joly (*loc. cit.*)

‡ The analysis of five specimens as given by Murray & Renaud (Challenger Report, Deep Sea Deposits, p. 389) gave:

	I.	II.	III.	IV.	V.
Ca O.....	1.69	1.26	1.27	1.34	1.19
Mg O.....	2.49	3.13	3.04	2.83	4.62
K ₂ O.....	2.52	4.21	3.86	3.36	0.95
Na ₂ O.....	0.90	0.25	0.25	0.27	0.62

Other analyses quoted by Roth, (Allgemeine und Chemische Geologie, Vol. 1, p. 559, 1879) gave a percentage of potassium (not K₂ O) varying from 2.8 to 7.3.

§ Murray & Renaud, *op. cit.*, p. 384.

and gravels of the Cambrian sandstone of North America, in the Quebec group of Canada and in the coarse Silurian sands of Bohemia. In the Mesozoic period it was more abundantly formed and its deposits are very marked in the strata of the Cretaceous division. It is also found in the Tertiary from the lowest strata to the highest of the series. It is thus shown that the formation of glauconite occurred in all the geological periods from the commencement of the Palæozoic Age to the present time and that thus a very large proportion of the potassium which the ocean would now contain, were it not for the formation of glauconite, has been removed from it.*

In the formation of glauconite, organisms appear to play a very distinct part and amongst these the Foraminifera are the most important. The decomposing organic matter of the dead forms liberates sulphur which combines with the iron in deposits to form sulphide.† This latter is converted into sulphuric acid which, acting on the fine clay sets free colloidal silica and ferric hydrate in a condition which promotes their union and the silicate so formed combines with potassium to form glauconite. It is obvious that organic matter is a very important factor in the process and that in the absence of animal organisms no glauconite would be formed, a view which explains the almost complete absence of this mineral from the deep sea areas, but it also postulates as decidedly, that before the appearance of living forms in the primeval ocean, there was little or no potassium eliminated from it, and this, taken in conjunction with the fact that in earlier pre-Cambrian times there could not have been much or any soil to affect the potassium in the waters discharged from the land areas, makes it quite clear that there was a period during which the potassium content of the ocean must have increased absolutely and that this was succeeded by a period in which the amount of the potassium ceased to increase or remained practically stationary, while decreasing relatively to other constituent elements. The beginning of this latter period coincided with the appearance of living forms in large numbers in the sea.

The history of sodium in the ocean has been one of uniform increase through all the geological ages. The addition that is to-day being made by river discharge is large and must have obtained as abundantly in the past. There have, on the other hand, been no important agencies which have served to eliminate it from the ocean. The great salt deposits, some of which are as old as the Cambrian, re,

* Forchhammer was the first to point out that potassium is being removed from the ocean. (British Association Report, 1844, p. 153.) From his analysis of Fucoids and of the metamorphosed Fucoid schists of Scandinavia he came to the conclusion that Fucoids constitute a very important factor in the process.

† Murray and Renaud, *op. cit.*, p. 389.

as is certainly the case with the Stassfurt beds, the result of the evaporation of land-locked arms of the sea,* and they are constituted of but an infinitesimal fraction of what is contained in the ocean. Sodium chloride, like other constituents of sea water, is carried landward with evaporation and rain clouds, but it appears to be returned to the ocean, without any perceptible loss, through the river discharge. The only method of elimination which at all possibly counts is that in which it is imprisoned mechanically in the sedimentary deposits during their formation. That sodium chloride is removed in this way has been pointed out and emphasized by Osmond Fisher, but there are no data which serve to indicate that this is a considerable factor in diminishing the sodium content of the ocean. All the known facts point in the contrary direction. There is no mineral in the course of formation, which is extensive or abundant in its distribution and which also requires considerable quantities of sodium for its production, and there are, further, no agencies acting in the soils which serve to remove sodium compounds from the percolating water.

In these considerations we find a full explanation for the relative proportions (100: 3.613) of the sodium and potassium which now obtain in sea water, and also for those which obtain in the river discharge of the globe. According to Murray's estimate for nineteen principal rivers, the proportions would be 100: 38.6. We may postulate from this that in the early geological periods of the pre-Cambrian period, when soils did not exist, the quantities of each element discharged by rivers or bodies of water derived from the land surface, were nearly equal. Since the primeval ocean, as pointed out above, contained these elements in almost equal quantities, this condition must have continued until long after soils holding organisms and organic matter had appeared, and even for an indeterminable period after organisms had made the ocean their habitat. The change in the relative proportions once begun must have gone on with extreme slowness, and oceanic organisms, at first wholly of the unicellular kind, must have, after acquiring a relation to these elements, just as slowly responded to the changes in the proportions of their medium.

The river discharge of the globe has been from primeval times adding also magnesium and calcium to the sea. According to calculations based on Murray's data, the proportions relative to the sodium shown in these are 134 and 591 respectively to every 100 of the latter. This is, of course, based on approximate estimations, and they may be incorrect,

* See G. P. Merrill's "Treatise on Rock and Rock Weathering and Soils," p. 120, 1897.

as they seem to be, if one scrutinizes the proportions that are found in rivers whose waters have been carefully analysed. There are only two rivers, the Amazon and the St. Lawrence, which give nearly the proportion of magnesium called for by Murray's estimates, while the Ottawa, the Mississippi, and the Nile give quantities much below that of the sodium, and the quantities of the calcium are found to vary very much for the different rivers. If we disregard Murray's estimates and base our observations on the analyses of the various rivers, we can safely conclude that, while the quantity of calcium added, except in the case of the Nile, is always, and sometimes very much, greater than the sodium addition, the latter does not probably exceed the amount of the magnesium discharged. In the ocean, however, the sodium, calcium, and magnesium have the proportions of 100, 3.91 and 12.0.

The comparatively low proportion of magnesium in sea water is explainable. In the first place, as pointed out above, there must have been in the primeval ocean but very little magnesium, owing to the conversion of all the chloride of magnesium into magnesia which is, except in minute quantities, insoluble. The conditions which so affected magnesium chloride left the chlorides of calcium, sodium and potassium unchanged, and in consequence these went into solution in primeval sea water, and were, therefore, as compared with magnesium, very abundant. Further, the ocean at first must have contained only traces of the latter element and the subsequent addition of it through river discharge would increase the amount in sea water, but not to such an extent as to make it overtake the sodium.

There is another factor which operated in limiting the amount of the magnesium. This is the tendency shown by the chloride to interact with the carbonate of lime when the latter undergoes deposition to form limestone, and, in consequence, this always contains carbonate of magnesia. When the latter exceeds 10 per cent. the mixture of the carbonates is given the conventional name of dolomite, and in some formations of this kind the magnesia is found greatly to exceed the lime. Dolomites are found in all the periods down to and including the Cambrian and even in the pre-Cambrian, it is associated with the crystalline schists.* An exact estimation of the magnesium so localized is impossible, but on the average it cannot be more than 10 per cent. of the quantity of the calcium due to deposition, so that the amount of magnesium removed annually from sea water must fall far behind that of the calcium. It follows from this that whatever were

* Zirkel, *Lehrbuch der Petrographie*, 1894, Bd. 4, p. 499.

the proportions of these two elements in primeval sea water, the proportions must have slowly changed, and as a consequence the magnesium must have gradually increased while the calcium practically remained stationary.

It must of course be admitted that magnesium is withdrawn from the ocean by organisms, but the amount thus removed is very small, and in no case is it an important method of eliminating the element from sea water. In the hard part of corals it is as a rule under one* per cent. and in the coralreefs it is less than that in amount, while the calcium constitutes nearly 40 per cent. Forchhammer's† analyses of the ash of sea weeds reveal a quantity of magnesium which he regarded as important, and he held that the Fucoids thus remove quantities of this element and deposit them in the beds which contain the solid substances of sea weeds as far as they are insoluble in water.‡ According to the analyses of Gödechens,§ the ash of Fucoids contains from 4 to 7 per cent. of magnesium. That the element is eliminated from sea water by these forms may be conceded, but it is doubtful if the quantity removed in this way is sufficient to affect materially in time the total amount retained in the ocean.

We may conclude, therefore, that in the formation of dolomites, of magnesia-holding limestones and chalk deposits, and, to a minor degree, in the activities of animals and plants, elimination of magnesium from sea water has always obtained; and, further, that the amount eliminated annually does not equal the amount of magnesium added to the sea by river discharge. This postulates a constant increase in the amount of magnesium in the sea; and in this respect it must be ranged with sodium, which increases in amount at a greater rate, since, so far as is known, there are for it no agencies of elimination in operation which compare with those affecting the potassium, the calcium, and even the magnesium. The sodium, therefore, though it is not added in greater amount than in the case of the latter, is increasing at a greater rate, and thus the proportion of sodium to magnesium in sea water is slowly altering. As pointed out above, the primeval ocean must have contained but an exceeding small quantity of magnesium, and the amount of the latter now in it is practically wholly derived from the leaching out of the land surfaces during the intervening ages.

As regards the calcium in sea water there is less uncertainty. The

* According to Forchhammer the corals, *Isis nobilis* and *Coralium nobile*, contain 6.30 and 2.1 per cent. respectively of magnesium carbonate.

† Roth, *op. cit.*, p. 616, where the results of analyses of a number of forms are given.

‡ *Op. cit.*, p. 159.

§ *Ann. d. Chem. und Pharm.*, Vol. 54, p. 351, 1854.

calcium of river discharge greatly exceeds in amount that of the three other elements, and yet it is less abundant than either in the ocean. If there were no elimination of calcium from sea water, the salts of the latter element would long have reached the point of saturation in the ocean. The present condition is easy of explanation. On the one hand, calcium separates from sea water through the formation of sulphate and carbonate of lime, which are to a high degree insoluble. This constitutes in part the origin of the gypsum beds and of the limestones of sedimentary origin. On the other hand the myriads of organisms that have their habitat in the sea have the lime "habit," and they consequently remove from solution enormous quantities of calcium. This is the case not only with all forms provided with exoskeleta and endoskeleta, into the composition of which lime largely enters, but also with those which exercise the precipitating effect on the calcium salts they absorb from sea water, the precipitation rarely going so far as to form a distinct deposit in the cells or tissues of the organism. This power to precipitate is universal, as shown by the fact that the capacity to form calcareous skeleta is almost universal, and this capacity is merely an enhancement of the power to precipitate. The latter, therefore, operating so largely, separates calcium from sea water, and on the death and disintegration of the organisms, the element is deposited on the sea bottom either as phosphate or carbonate of calcium.* These deposits, owing to the fact that they contain few calciferous fossils, are regarded as due to chemical reactions alone; but if they are, sedimentary limestones should be of a more uniform distribution, whereas we find them more or less localized. The explanation that they are due to protoplasmic "secretion" and not to either chemical reaction or skeletal deposition in living forms accounts for much, and indicates what a factor living protoplasm, animal and vegetable, is in the separation of calcium from sea water.

Sterry Hunt† advanced the view that in the primeval ocean the chief salts were chlorides of calcium and magnesium, and that the constant, large output by river water of carbonates of sodium and potassium, and particularly of the former, affected a conversion of these into carbonate of lime and chlorides of sodium and potassium which were retained in solution, while the carbonate was deposited. The objection to this view is that, if it is correct, the conversion ought to have taken place in the pre-Cambrian period, and, therefore, there ought to be extensive limestone deposits in the rocks attributed to that period.

* Sterry Hunt, *op. cit.*, pp. 80 and 311.

† *Op. cit.*, pp. 2 and 41.

There is, indeed, in these rocks only a small amount of crystalline or other limestone, and there appears to be still less in the divisions of the Huronian, which, as pointed out, have a thickness in the Lake of the Woods and Rainy Lake districts, according to Lawson,* aggregating 50,000 feet, all representing sedimentary formations. What limestone and gypsum are present in pre-Cambrian rocks can very well be attributed to the occurrence of calcium salts in the oceans of the Archæan in quantities, however, which could not have very greatly exceeded those which obtain to-day in sea water.

V.—THE RELATION OF THE SALTS IN THE OCEAN TO PROTOPLASM.

From the considerations advanced in the preceding section of this paper, it follows that the ocean has been, and is now, slowly changing, not in its composition, but in the proportions in it of the various elements to each other, and that, as a consequence, it is now in this respect greatly different from what the primeval ocean was in the period following the first condensations of water vapour on the rock crust of the globe. It may again be noted that in all these changes there are two distinct periods. In the first, or older, life was not represented except towards its close, and therefore, the only factors engaged in eliminating any of the elements from the sea were purely chemical ones such as are illustrated in the precipitation of lime as carbonate and sulphate and of magnesia as carbonate. In this period the elements must have differed in amounts from each other less markedly than they do to-day, and the constant addition to these from the discharge from the land surfaces did not tend to alter, even after a very long interval, the proportions which first obtained. This period must have terminated some considerable time after the appearance of living forms on the globe, and especially only after the adaptation of vegetable forms to a land life, and the consequent production of soils. The second period could not have begun at once after the appearance of living forms, for these must first have acquired a relation to the elements and then have developed the habit of disposing of the various salts which they took out of the sea water. This period may well be supposed to have begun when there had developed not only a considerable diversity of forms in the sea, but also the organisms which contribute to the production of organic matter in soils. In this period the removal of potassium from the land surfaces decreased,

* *Loc cit.*

and the combination of this element with argillaceous matter at the bottom of shallow portions of the sea began. As a result the amount of potassium in sea water became stationary. At the same time the removal of calcium on a larger scale than obtained in the preceding period commenced and this checked the increase of calcium salts.

The first forms of life in the primeval ocean were undoubtedly unicellular, and they were probably also organisms which presented features intermediate between those of the vegetable kingdom on the one hand, and those of the animal kingdom on the other. These forms must have persisted for a period of unknown but very great duration, for in them developed not only a nucleus but also the capacity on the part of the latter to divide in the remarkable and complicated manner illustrative of karyokinesis, and which is characteristic now of the cells of both kingdoms. This process of division, so alike in its main features in animal and vegetable cells, must have become fixed before specialization had gone so far as to evolve both animal and vegetable types, for, had it been otherwise, there would have been greater differences in the process in animal and vegetable forms. That the process has continued practically unchanged in all the intervening millions of years shows how deeply fixed in the organism this morphological habit has become, and, therefore, the act of fixation must have taken an incredibly long period of time during which the ocean was changing, not in the relative proportions to each of the elements it contained, but in the absolute amounts of these.

During this long period, these organisms, neither distinctly animal nor distinctly vegetable, exposed as they were to action of these same elements, must have acquired a relation to them as fixed as the karyokinetic process was becoming. Their protoplasm had established all its normal processes in the presence of potassium, sodium, calcium, and magnesium in certain proportions in sea water, and, after the lapse of the long period of time required for the elaboration of the karyokinetic method of division, these processes became unalterably dependent on the presence of the elements in the proportions which then prevailed. Without this fixed relation life could not continue, and when specialization into animal and vegetable forms occurred this fixed relation was transmitted to the forms of both kingdoms. How long these latter forms remained unicellular cannot, of course, be surmised, for there are no means of determining the length in time of this or any part of the pre-Cambrian age, but that it was of very great duration can hardly be questioned, and it must have strengthened the relation which obtained between protoplasm on the one hand and the elements in certain pro-

portions, on the other.* In consequence, their descendant forms inherited this relation, and transmitted it to the forms and species which arose through variation and other causes. When multicellular forms arose these were endowed with the same relation.

The proportions of the elements in the early pre-Cambrian ocean with their long action on protoplasm must then have conferred a more or less fixed property on the latter and, in consequence, living matter, whether animal or vegetable, now shows in its ash proportions of the elements greatly different from those found in the media in which it lives or in the circulatory fluid which bathes it. This relation or property resists change even after exposure to altered conditions for a very long period of time. Before the circulatory fluid (blood plasma) was established in multicellular animals, a great change must have occurred in the proportions of the elements in the ocean, a change which would account for the wide differences between the proportions in the protoplasm or tissue on the one hand, and those in the blood on the other.

The proportions of the elements in living matter are due then to conditions which obtained in the ocean far back in the pre-Cambrian age, while those in the blood or plasma are due to conditions which occurred in the ocean long after this and yet before the beginning of the Cambrian period. The proportion of potassium to sodium in blood plasma is nearly† double what it is in the ocean and therefore that difference must have resulted in the period that has elapsed since the rudiments of a circulatory system were developed in those Metazoan animals which gave rise to Vertebrates.

As pointed out above, it is difficult to obtain the exact proportions of the sodium, potassium, calcium and magnesium in living matter, for, except in muscle fibre, protoplasmic structures cannot in sufficient quantities be freed from adherent material which carries these elements in very different proportions. Calcium exists in tissues apart from the protoplasm and as precipitates or deposits, and according to recent observations which I have made, this is true in a very large degree of

* Geologists concede a very long time to the pre-Cambrian, a duration which, according to the different estimates, ranges from one-third to four-fifths, and even nine-tenths, of the whole geological period. The very fact that all the chief types of animal life, and perhaps also of vegetable life as well, appeared before the close of the pre-Cambrian age, indicated that the latter was of inconceivably long duration.

† Amongst the oldest and highly specialized forms are *Olenellus* and the Brachiopods of the Cambrian. The oldest Vertebrate remains are in the Trenton division of the Silurian, more recent than the Cambrian, but these are "ganoid" in character and this fact postulates a long preceding period of development out of Protovertebrate forms which therefore could not have first appeared much later than the beginning of the Cambrian. The circulatory system of Vertebrates accordingly has a history which began in the pre-Cambrian age.

potassium. With regard to this element it may be said that active living matter has the power of absorbing it in large quantities and disposing of it in an inert form by precipitating it at the peripheries of cells or in inert organic masses within them, and, as a consequence, the ash of animal and vegetable cells shows a larger quantity of potassium than the protoplasm of the cells required. This illustrates how difficult it is to determine the primitive and fixed proportions of potassium and calcium, and further, how little we should depend, even in the case of muscle, on the analyses of the ash of organs or organisms, for this purpose. If a sufficient quantity of *Amœbæ** could be obtained for analysis it might yield results of value but until that is done, the exact proportions of sodium, potassium, calcium and magnesium must be a matter for conjecture. It can scarcely be that the proportions found in muscle represent even approximately those which should obtain in undifferentiated protoplasm or cells.†

VI.—EVIDENCE FROM THE LAKES AND RIVERS OF THE PRESENT PERIOD.

It may be pointed out that in the composition of the rivers, large lakes, and seas of the world, there is evidence confirmatory of the view that potassium and calcium predominated in the pre-Cambrian seas. The conditions, of course, which contribute to the composition of the lakes of to-day are not the same as those which existed when the oceans of the globe were formed. There are but infinitesimal traces of the chlorides of calcium and potassium in the rock crust or sedimentary strata, and, further, there are, apart from the deposits of salt, and that amount of it due to rainfall, but small quantities of sodium chloride which can to-day come under the leaching action of water. There are also soils to alter the proportions of the chemical elements derived from them.

Nevertheless it happens that in lakes surrounded, either wholly or

* Fresh water, unicellular animal organisms are apparently free from excess of the elements. They are, as a rule, free from potassium, at least in such quantities as are found in other organisms.

† According to J. Katz (*Pflüger's Arch.*, vol. 63, p. 1), the proportions in muscle from different animals are:

	Na.	K.	Ca.	Mg.
Man.....	100	400	9.3	26.4
Dog.....	100	384	7.86	23.1
Rabbit.....	100	870	40.0	60.5
Pike.....	100	1415	145.0	105.0

These and other results of the same observer are open to the objection that no effort was made to get muscle fibre free from all adherent tissues. Visible blood vessels, tendons, nerves and fat were indeed removed but these constitute only a part of the non-muscle portions of the tissue and they may be the cause of the variations shown in the results.

partially, by regions in which pre-Cambrian formations occur, or are the only apparent rocks, the potassium predominates over the sodium. For example, in the water from Reindeer Lake, which is situated 400 miles directly north of Lake Winnipeg, Professor Adams found the potassium to exceed very greatly the sodium. In the water from the Churchill River, as well as in the water from the Saskatchewan River above the junction of the Big Stone River, the potassium is much richer than the sodium.* These rivers drain rocky areas chiefly of the pre-Cambrian type. Rocks of the primitive kind, therefore, contrary to the prevailing opinion,† supply to the water which comes in contact with them more potassium than sodium.

Even in the case of Lake Superior which draws its supply not only from the primitive rock region on its northern side, but also from the areas covered with soils of alluvial and drift origin on the south, the potassium is about equivalent to the sodium. In the lakes of the Bavarian Highlands, Rachel See, Würm See and Ronig See, the potassium is twice in amount that of the sodium. In Lake Zurich the potassium exceeds the sodium. In Lake Geneva, in Pyrenean and Vosgean Lakes and in those of Russia, Armenia and Central Asia the potassium is approximately two-thirds of the sodium. It is probable that if proper methods for estimating potassium had been current in his day, C. Schmidt would have found for the lakes of Russia, Armenia and Central Asia a higher potassium value than he obtained, for the methods then in vogue for the determination of the element in the presence of sodium were very faulty and gave very low results. It is probable also that this may explain the low value found by Sterry Hunt for the potassium of the Ottawa River, whose waters, as well known, are derived largely from Archæan regions.

The Tables A and B show further that, in nearly all cases, the calcium is very abundant. In the Nile only, amongst the rivers, is it less than the sodium, while it very greatly exceeds it in the rest. In the lakes it is very abundant relatively, with the exception of the Rachel See and Lake Onega. In the Bavarian lakes, Lake Geneva, Lake Zurich, and some others, it is exceedingly abundant relatively.

The magnesium is always less than the calcium, and the relative difference is sometimes very great. It may fall below the sodium, but, as a rule, it is greater in amount.

These proportions, one can readily understand, must have been

* F. D. Adams *Geo. and Nat. Hist. Survey of Canada*, 1880-2, p. 6, 4.

† This opinion is based largely on the fact that the potash feldspars are difficult to decompose while the soda feldspars readily undergo decomposition.

uniformly maintained for an indefinitely long period. It may even be claimed that, in the case of Lake Baikal, of Reindeer Lake, and other lakes supplied from Archæan areas the proportions have obtained from pre-Cambrian times, and further, that the river discharge of that period, coming as it did from pre-Cambrian rock areas wholly, would contain the four elements in these or similar proportions. That would postulate that the primeval ocean was merely a gigantic body of fresh water, in which the sodium, potassium, calcium, and magnesium obtained in quantities and proportions as they now obtain in a lake situated in Archæan area. As already pointed out, these proportions gave place to others, and to-day, as in the past, the relative amounts of each element are changing, so that in a few million years hence the composition of ocean water will be appreciably different from what it is now.

One can, indeed, illustrate what changes have taken place in the ocean by reference to such a large body of fresh water as Lake Superior. If the latter were to lose its outlet no doubt its area would be larger than it is now, but when that had attained a certain extent the evaporation would balance the inflow as in the case of the Caspian Sea, and in consequence the salts held in solution would constantly increase in amount, but each at different rates up to a certain point, when the proportions would begin to approximate those in ocean water. One cannot of course say that this is what has happened in the case of either the Caspian or the Sea of Aral, for these bodies of water were connected with the ocean as late as the beginning of the Tertiary age, but it may be pointed out that if their composition was, to start with, the same as that of the ocean in Tertiary times, their present composition is strong evidence of the effect that the salts derived from leaching of the land areas have in modifying the proportions, for in that respect either is markedly different from the other and from the ocean.

The Great Salt Lake of Utah may be adduced as an instance of the change of a body of fresh water into one which presents a high degree of salinity and which in the proportions of its salts is remarkably not unlike the ocean. This lake, which is in part of the area covered by the glacial Lake Bonneville, is considered by G. K. Gilbert to have been a body of fresh water about 25,000 years ago. He arrived at this result by determining the discharge of chlorine into the lake by river water and comparing it with the quantity at present obtaining in the lake. Lake Bonneville had* an outlet delivering its waters into a tributary of the Columbia River and thus the lake was kept fresh. When, however, this outlet was lost, changes climatic and physical operated to reduce

* Monographs of the U. S. Geol. Survey, Vol. 1, Lake Bonneville, 1890, p. 254.
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the volume of water, and, evaporation keeping pace with the inflow, a concentration of the salts held in solution took place. An examination of the present sources of inflow shows that these do not contain the sodium, potassium, calcium and magnesium in the relative proportions which are found in the lake. Gilbert estimates that it would take only eighteen years to give the lake through its fresh water inflow, all the calcium it now contains and that 850 years would to this end be required for magnesium. He does not deal with the case of the potassium of which the analyses he reports show only traces in the inflow water, but this also may have been due to faulty methods of determining that element. These latter seem to be the only explanation for the great discrepancy between the amounts of potassium found by Talmage* in 1889 and Bassett† in 1873‡.

Short as is the extreme period required by Gilbert's calculations to affect all the changes in the composition, it has epitomized the history of the ocean. Even if we postulate that the primitive rock crust of the globe in pre-Cambrian times contained more sodium chloride than what is found now in Archæan formations, there is also more of this salt in the strata of later geological periods which cover the drainage area of Utah Salt Lake. Of course there is not a complete parallel between the latter and the ocean, for the relative proportions are not exactly the same, but their approximate similarity is striking, and, it may be added, very convincing as to the extreme probability of the thesis maintained above.§

TABLE A.

	Na.	K.	Ca.	Mg.	SO ₃ .	Cl.	Si.	Fe.
1. St. Lawrence ... 100	22.9	638.0	143.4	136.0	223.0	343.0	....	....
2. Ottawa 100	64.2	416.7	82.5	67.3	224.3	402.0	....	....
3. Mississippi 100	35.5	462.0	82.0	17.1	8.4	85.4	17.0	....
4. Amazons 100	72.6	1,089.0	135.6	36.0	90.0	....	....	....
5. Nile 100	22.2	75.1	41.5	18.5	16.0	44.4	....	....
6. Assinaboine 100	10.5	122.0	69.4	127.9	50.0	....	....	....
7. Red River 100	12.3	133.3	83.2	190.0	91.4	....	....	....
8. Nineteen Rivers (Murray) 100	38.6	590.9	134.2	197.6	53.5	145.3	37.9	....

* Science, Vol. 14, 1889, p. 445.

† Chemical News, Vol. 28, 1873, p. 236.

See Table B, Utah Salt Lake, 26 and 27.

§ In Lake Shirwa, according to J. E. S. Moore, ("The Tanganyika Problem," 1908, p. 22,) we have a lake which was once fresh, but has become salt through the loss of its outlet. So far as I know no analyses have been made of its waters.

TABLE B.

LAKES AND SEAS.

	No.	K.	Ca.	Mg.	SO ₃ .	Cl.	Si.	Fe.
9. Superior	100	97.2	1,015.0	208.0	27.5	103.2	19.3	....
10. Rachel See	100	199.4	13.0	....	....	17.5	....	1.6
11. Würm See	100	223.9	2,445.0	809.0	....	....	....	....
12. Walchen See	100	117.7	2,557.0	808.5	....	....	....	....
13. Ronig See	100	207.9	5,812.0	588.8	....	....	....	....
14. Schlier See	100	96.4	3,141.0	661.0	....	....	....	....
15. Lac Gaube (Pyrenean)	100	66.3	421.0	17.9	....	....	....	....
16. Lac Gerardmer (Vosges)	100	70.4	117.6	29.8	....	....	....	....
17. Lake Geneva	100	74.5	2,345.0	341.3	....	55.0	1,806.0	....
18. Lake Zurich	100	111.7	1,843.9	272.0	441.0	36.0	60.8	....
19. Lake Peipus	100	75.2	929.5	159.9	18.5	134.0	13.3	3.4
20. Lake Onega	100	71.4	67.3	51.4	33.4	104.7	36.9	2.2
21. Lake Tschaldyr (Armenian High- lands)	100	59.3	219.3	45.7	88.2	65.3	172.1	5.5
22. Lake Baikal	100	58.9	399.6	60.6	98.5	41.7	16.1	17.3
23. Sea of Aral	100	2.38	18.6	24.2	113.0	156.0	....	....
24. Caspian Sea	100	3.35	9.4	22.7	80.0	163.7	....	....
25. Dead Sea	100	28.4	40.3	1.27	2.0	556.1	....	....
26. Utah Salt Lake ..	100	3.22	1.22	7.81	14.9	169.2	....	....
27. " " ..	100	25.8	1.56	7.82	19.1	192.2	....	....
28. Ocean	100	3.613	3.91	12.0	20.9	180.9	....	....

REFERENCES FOR ANALYSES.

- 1 and 2. Sterry Hunt, *Phil. Mag.*, 4th series, Vol. 13, p. 239, 1857.
3. Warren Upham, *The Glacial Lake Agassiz*, United States Geol. Survey, 1895, p. 543.
4. Meillard Reade, *Am. Journal of Science*, Vol. 29, p. 295, 1885.
5. O. Popp, *Annalen d. Chem. und Pharm.*, Vol. 155, p. 344, 1870.
- 6 and 7. Warren Upham, *Op. Cit.*, p. 542.
8. John Murray, *Scottish Geogr. Mag.*, Vol. 3, p. 76.
9. Warren Upham, *Op. Cit.*, p. 542.
10. Johnson und Lindtner, *Liebig's Ann. der Chem.*, Vol. 95, p. 230, 1855.
- 11-14. Ad 'f Schwager's Analyses in Willi Ule's *Der Würm See (Starnbergersee)*
in *Oberbayern*, Leipzig, 1901.
- 15-17. Delebecque, *Les Lacs Français*, Paris, 1898, pp. 197-205.
18. F. Moldenhauer, *Schweizer Polytechn. Zeitschr.*, 1857, II., p. 52. (Reference in
Kopp and Will's *Jahresber. der Chem.*, 1857, p. 724).
- 19-22. C. Schmidt, *Bulletin's Acad. Imp. de St. Petersburg*, Vol. 28, 1883, pp. 245-6.
- 23 and 24. C. Schmidt, *Bull. Acad. Imp. de St. Petersburg*, Vol. 20, pp. 134 and 143, 1875.
25. R. F. Marchand, *Journ. für Prakt. Chem.*, Vol. 47, p. 365, 1849.
26. J. E. Talmage, *Science*, Vol. 14, 1889, p. 444-6.
27. H. Bassett's Analysis, reported by G. K. Gilbert, *Lake Bonneville*, U. S. Geol. Sur-
vey Monographs, p. 253, 1890.
28. — Dittmar, *Challenger Report, Physics and Chemistry*, Vol. 1, p. 203.

SUMMARY.

The points discussed in the preceding pages may be summarized as follows :—

1. The composition of the ocean represents the result, on the one hand, of the leaching action of water on the land surfaces of the globe continued throughout all the geological periods, and, on the other, of the chemical and other agencies modifying or enhancing the power of sea water to retain in solution the mineral constituents derived from the land surfaces through river water since the beginning of the primeval period.

2. The relative proportions of the elements, and especially of sodium, potassium, calcium, and magnesium, in river discharge are not parallel to those of the same elements found in the sea. In river water, the calcium is always more, and the potassium less, abundant than the sodium, while the magnesium appears to approximate in amount the latter. In the sea, on the other hand, the sodium is much more abundant than the other three elements, and this is due to the continuous precipitation of a very great portion of the calcium added by rivers as carbonate, to the subsequent fixation in the limestone so formed of the magnesium as carbonate, and to the removal, continually taking place, of potassium, which is affected through animal and vegetable forms, and its consequent fixation in submarine deposits as glauconite and other potassium-holding minerals. The calcium and potassium appear to be stationary in amount, while the magnesium added by river water appears to exceed in amount that removed from the sea, and, in consequence, is slowly on the increase in the ocean, but its rate of increase is far behind that of the sodium.

3. The relative proportions of the elements in the ocean have, therefore, always been changing, and these proportions must have been, in the earlier geological periods, very different from what they are now. In the ocean of the earliest period the relative proportions of the elements approximated those found in river discharge, or rather those found in fresh water shed from areas covered with Archæan rocks. In this the potassium approaches the sodium in amount while the magnesium exceeds the latter, and the calcium is relatively very abundant.

4. This condition must have continued until living forms made

their appearance in the ocean when the gradual elimination of the magnesium, and particularly of the potassium and calcium, began. The forms were in all probability unicellular, and as the period must have been of great duration, the organisms and their protoplasm acquired a fixed relation to the four elements.

5. With the appearance of vegetable land forms and the formation of soils the removal of potassium from the land to the sea by river water diminished, and this, in conjunction with the elimination of the element from sea water by organisms, made the amount in the sea stationary. Through the action of living forms the calcium also in sea water has been kept stationary since that remote period.

6. In the transition from the ocean of the more ancient composition to that of the present, the unicellular forms became multicellular, and developed circulatory systems, the vascular fluids of which were at first simply modified sea water. In the blood plasma of Vertebrates, the three elements, sodium, potassium, and calcium are in relative proportions strikingly like those which now obtain in sea water. The magnesium only is considerably less than it is in sea water. The whole is due to heredity, the proportions of the saline constituents of the plasma being a reproduction of the proportions which obtained in sea water when circulatory plasmata were developed.

7. The proportions of the four elements which obtain in living protoplasm are as yet unknown, for the latter has the power of precipitating the potassium, calcium and probably the sodium and magnesium as inert compounds in itself or in its adventitious structures, and thus analyses would comprehend the inert material as well as the quantities of these elements which are actively participating in the processes of the living substance. If we could determine the latter quantities alone we could regard them as a representation of the proportions obtaining in primeval sea water to which the protoplasm of unicellular organisms had established a fixed relation.

8. That such a relation could be inherited may be inferred from the fact that the karyokinetic process, being practically the same in the animal and vegetable cell, has continued unchanged in both from the primeval period when the karyokinetic process first developed in a parent unicellular organism neither distinctly animal nor distinctly vegetable. This indicates how marked an influence heredity wields.

9. Briefly, animal as well as vegetable protoplasm owes its relations

to the elements sodium, potassium, calcium and magnesium to the composition of sea water which obtained when all forms were unicellular just as the blood plasma owes its relations to the same four elements to the composition of sea water which prevailed when circulatory fluids were established. In other words the relation of protoplasm to salts is due to the action for ages of sea water, for incalculably long periods of time, on the living matter of unicellular organisms.

